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Assessment of Potential Material Reprocessing of Erdenet Mine Tailings

Bachelor Thesis

by

Azjargal Sengedorj

Raw Material Processing Engineer

Supervisor 1 / Examiner 1

Mrs. Munkhjargal Chimeddorj

Supervisor 2 / Examiner 2

Prof. Dr. Battsengel Baatar

Ulaanbaatar, Mongolia, 2020.06.07

Statutory Declaration

Azjargal Sengedorj

14731299848076

Last Name, First Name

Student ID Number

I hereby affirm in lieu of an oath that I provided the submitted bachelor thesis

Assessment of Potential Material Reprocessing of Erdenet Mine Tailings

I did not use any sources other than those stated. In case the work is additionally submitted on a data medium, I declare that the written and the electronic form are completely identical. The work was not submitted in the same or similar form to any examination authority.

Ulaanbaatar, Mongolia

2020.06.07

Place, Date



Signature

Acknowledgment

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Abstract

The objective of this study is to define possible ways to reprocessing Erdenet mine tailings with potential metal recovery. These tailings have relatively high copper and molybdenum concentration (e.g. tailings III has Cu: 0.2-0.5%, Mo: 0.1-0.2% content), some of which are concerned as reusable deposits. But the measured concentration of metals does not have a homogeneous population over the whole tailings due to settling of the materials, reclamation of process water and drying of the materials, etc. The tailing facility is one of the largest in the world with a total area of 18.6 km². Over 40 years of history of Erdenet processing plant, the tailing has been collected in the tailing dam and now becomes the biggest resource for research.

The surface samples were taken from 5 different areas with various depths. Furthermore, physical analysis (Size distribution analysis) and chemical analysis (X-ray Fluorescence element analysis) were done.

Based on physical and chemical characteristics, the possible applicable method to reprocessing tailing was investigated. As a result of this study, the possibility of using Erdenet Mine tailings has subjected to technical and economic considerations.

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Table of acronyms

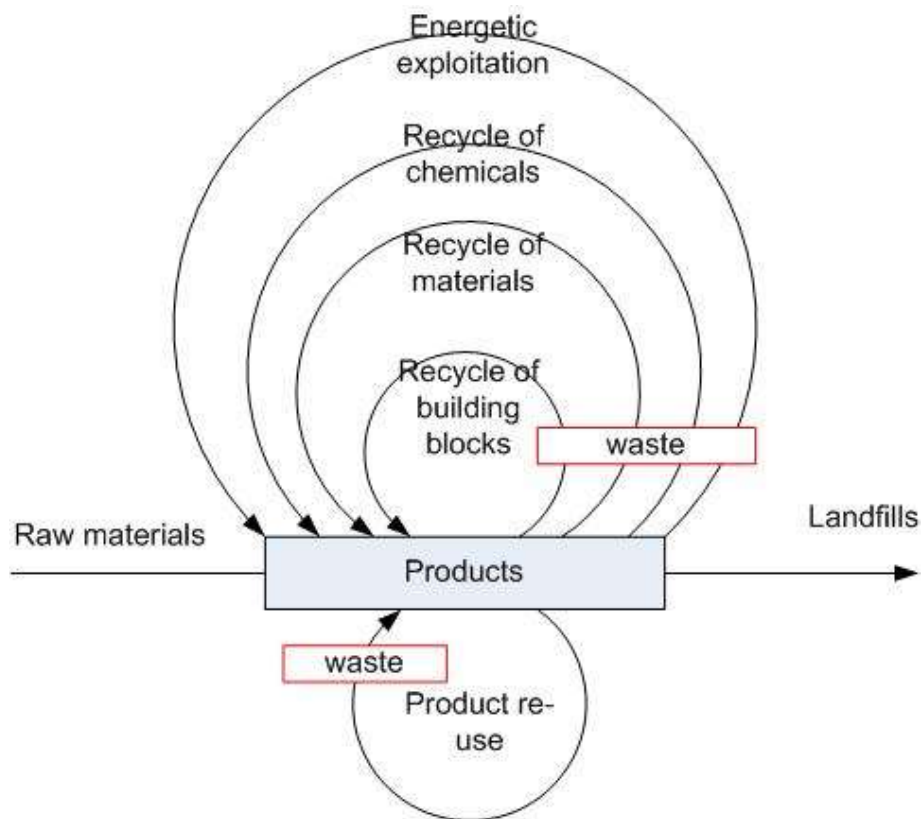
ADRIANA	Airborne spectral Detection of Reusable Industry materials in tailings facilities
AMD	Acid Mine Drainage
CGL	Central Geological Laboratory
CMF	Copper Molybdenum Flotation
COVID-19	Coronavirus Disease 2019
EMC	Erdenet Mine Corporation
GMIT	German Mongolian Institute for Resources and Technology
LOD	Limit of Detection
PP	Processing Plant
ppm	particle per million
PVC	Polyvinyl chloride
TSF	Tailings Storage Facility
XRF	X-ray Fluorescence

1 Introduction

1.1 The problem statement

The thesis is mainly focused on the sustainable use of Erdenet mine tailing waste. Sustainability establishes the fact of saving any raw material or resources for industry and avoiding wastes, which is a great deal to solve in the perspective of not only environmental views but also economic views of taxes and social costs regarding public health.

Figure 1-1: Sustainable production (Hampe, 2020)



The lifecycle of any material follows the pattern shown above. The raw materials are meant to make products after getting treatment or re-treatment material goes to landfills. To reduce the amount of material which goes to landfill, and to increase efficiency and recovery of material, recycling the waste material of process is an optional way. Recycling waste can be considered at each possible level of structure of the material. This concern has been developed as increasing demand for raw material and decreasing the availability of metals. Especially mining and processing operations have the production of as much as the amount of raw material of mining waste. So that recycling or reprocessing mine waste has a big influence on the sustainability of mine. Moreover, in recent years significant metal, metalloids, and rare

earth elements that have no application in the past have been applied to several manufacturers and metallurgy.

In Mongolia, we are also dependent on the import of raw material and metals. The production of copper concentration has a big influence on the economics and development of mining and manufacturing. Copper containing either sulfide or oxide ores generally low value of bulk metal copper and co-elements, Ag, Au, Pb, Mo, and Zinc, that have considerably owned production infrastructure. And co-elements, Pd, Ir, Co, Rh, Pt, Os, Ru, and so on, that have no or limited economic efficiency. It gives us a huge potentiality to reuse these co-elements which ended up in residues and goes to landfills. The concentration of those copper ores is usually a flotation method. The flotation tailing contains lost copper, molybdenum, and additionally reagents. So that we can conclude that there are 2 main ways to reprocess tailings which are the re-flotation process to recover valuable metals in tailings and recycling tailings to remove contaminant metals that may have an environmental impact in further production.

Hypothesis 1: Re-flotation of mine tailings with the chosen amount of reagents is efficient and recovery is around -60%.

Hypothesis 2: Re-processing tailing with additional flotation line and additive reagents to maintain the recovery of valuable metals while reducing the amount of tailing is a possible method

Hypothesis 3: Re-using tailing material, which has a high content of silica and some valuable contaminant, for making ceramics and construction materials.

1.2 The aim and the objective of the thesis

The objective of the thesis work is to study possible ways to reprocessing copper mine tailings. There are many suggestable ways to process tailings and big data laying on the whole history of copper production. The aim is to define the most suitable and economically efficient way to process tailings among other possible methods with theoretically and educated conclusion.

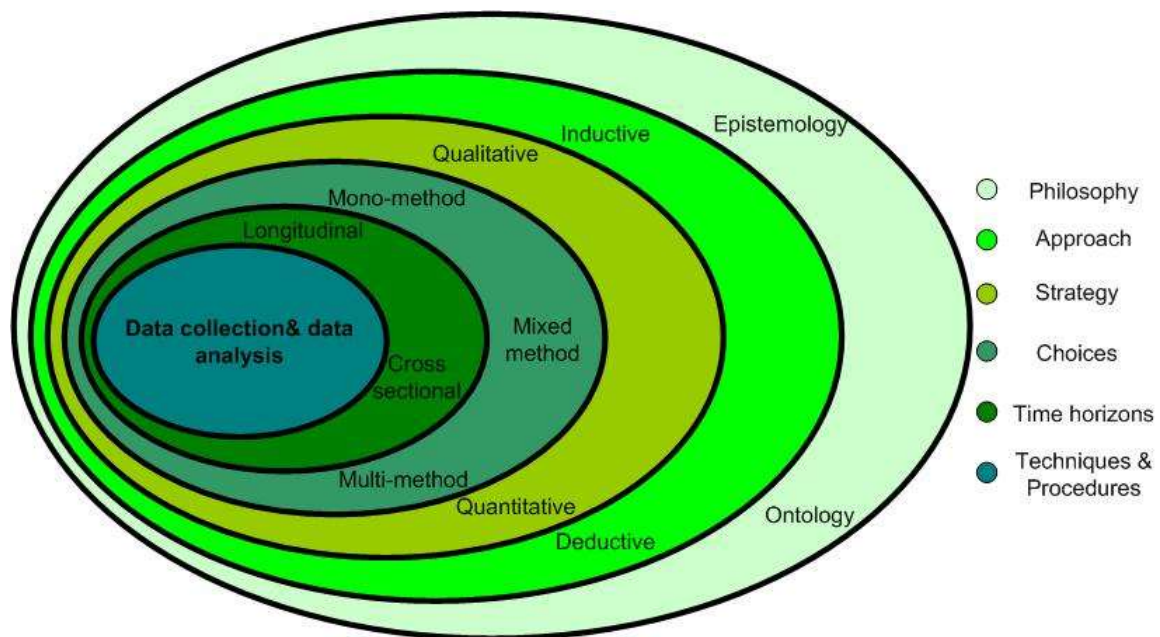
1.3 The research methods and procedures

The first step to determine the research methodology is to define the thesis perspective. There are several different perspectives, among that 2 major perspectives are developed and used generally, quantitative and qualitative. The quantitative perspective involves quantitative studies, follow facts and causes of the phenomenon without committing subjective analysis, and priors to measurements and investigate the relationships. The qualitative perspective involves qualitative research methods, priors

to meaning, and understanding, which is usually discovery or process-oriented. A qualitative perspective refers to personal experience on the field, which is seen as a flexible design, and a hypothesis can be formulated during data formulation. Whereas a quantitative perspective is verification, and result-oriented and hypothesis must be established before data formulation and sequential method to collect data. To sum up, this thesis follows a quantitative perspective because I lack subjective data regarding selected material, which I draw the data from. In this case, I would prefer a very sequential and valid methodology to get a reliable outcome.

The thesis result was written mainly research-based, secondary data is collected to analyze. Some data is primary but that can not build the whole estimation so I chose the research-based method to get realistic results and to follow a guaranteed methodology. I have chosen the Onion research methodology or Saunder's research methodology. The onion research methodology was developed by Saunders et al., 2007 and has different six layers, occurring in order, start from the outer layer to the core these are taken apart as research philosophy, research approach, research strategy, research choices, time horizons and techniques, and procedures. (H, 2020)

Figure 1-2: Onion methodology scheme (H, 2020)



The onion methodology has its procedure to follow and each level of that the path I have to choose was dependent on the objective of the thesis. The data collection and analysis would be narrowed down with onion methodology and at each level of that data would be more qualified and easy to get results.

The first layer of the onion is the philosophy of the research. Philosophy has 2 major types, positivism which includes methods of natural science, most likely deals

with the deductive approach with initial theories and hypothesis, and investigates more specific details, and Interpretivism which deals with the assessment of words, actions, and behaviors that can not be evaluated scientific theory and data. It concludes that positivism is more suitable for this and more likely we have decided on that with a research perspective.

The second layer of the methodology was to choose the research approach, which is generally divided into the deductive and inductive approach. The deductive approach starts with a particular hypothesis, then develops with information or patterns, checks the hypothesis, and develops a comprehensive theory from that. Otherwise, the inductive approach starts with general information then investigates into more precise details and confirms a specified hypothesis. The research approach is decided on the deductive approach, which I would say that starts with a specific hypothesis, that reprocessing of copper mine tailing is efficient and its recovery is economically efficient, and based on the research and analysis I would confirm the hypothesis is true or false.

The third layer of the methodology is the research strategy, which is kind of similar to the research perspective qualitative or quantitative. We have already chosen that our research is quantitative.

The fourth layer of onion methodology is research choice which is a mono-method, mixed-method, or multiple methods. Mono method uses only one research approach, qualitative or quantitative. The mixed-method uses both qualitative and quantitative approaches to get a more reliable and valid result. To choose between those methods, if I consider that data collection and data analysis would follow a quantitative approach whereas the result would be written with my own opinion, and based on my own experience from research, the choice would be mixed method of a quantitative and qualitative approach.

According to the research onion, the methodology time horizon is which specified time the project or research is expected to finish. Time horizon can be longitudinal, which collection of data is repeated over a long time and focuses on the change over time, or cross-sectional, that is based on existing data but has to be collected and examining the particular occurrence at a specified time. So the time horizon would be cross-sectional because the data has already existed on Erdenet Mine where I have to draw the data and analyze for a specified reason, recycling the tailings.

After completing each layer of the research methodology, data collection and analysis is dependent on me, who have to choose how and where my data is collected

from, and the reliable and reasonable choice of the methods which would be used for data collection.

1.4 The scope of the research

After choosing what method to use, data source selection comes to next, where I draw the data from and define the scope of the research, the range of aspects of the thesis covers. In the previous section, the thesis aim and objective were pointed out as recycling of copper mine tailings, and the research methods were chosen as onion methodology.

The thesis is written on the case of Erdenet mine tailings of Erdenet Mine Corporation. The field of the research was chosen because of these reasons:

1. Erdenet Mine has a great history of over 40 years in copper-molybdenum production. As much as they have produced copper and molybdenum production there is more history behind as mine tailings. So that this is a great data source to draw, which is attracting many researchers with the possibilities. It was a great opportunity to liven up the dead, or I can say inactive, data and based on that future possible actions were assumed.
2. GMIT is currently working on project ADRIANA. Within the frame of this project ADRIANA, Erdenet Mine Corporation allows exchanging some information and data. Within the frame of the project, 40 samples were taken from the field, Erdenet tailing dam, and analyzed. I was provided some data regarding this project and was able to compare data of my analysis with the existing data.

Because of the COVID-19 crisis, the thesis plan was changed, which was originally planned to do XRF analysis, Re-flotation experiment, and possible experiment to make construction material sample. The experiments were done only for size analysis and XRF elemental analysis due to the time limit and restriction of activities at university. To sum up, the aspect of the research is directed to the elemental composition of tailings and based on the characteristics of the material, and in which way we can reprocess the tailings is more efficient, would be concluded.

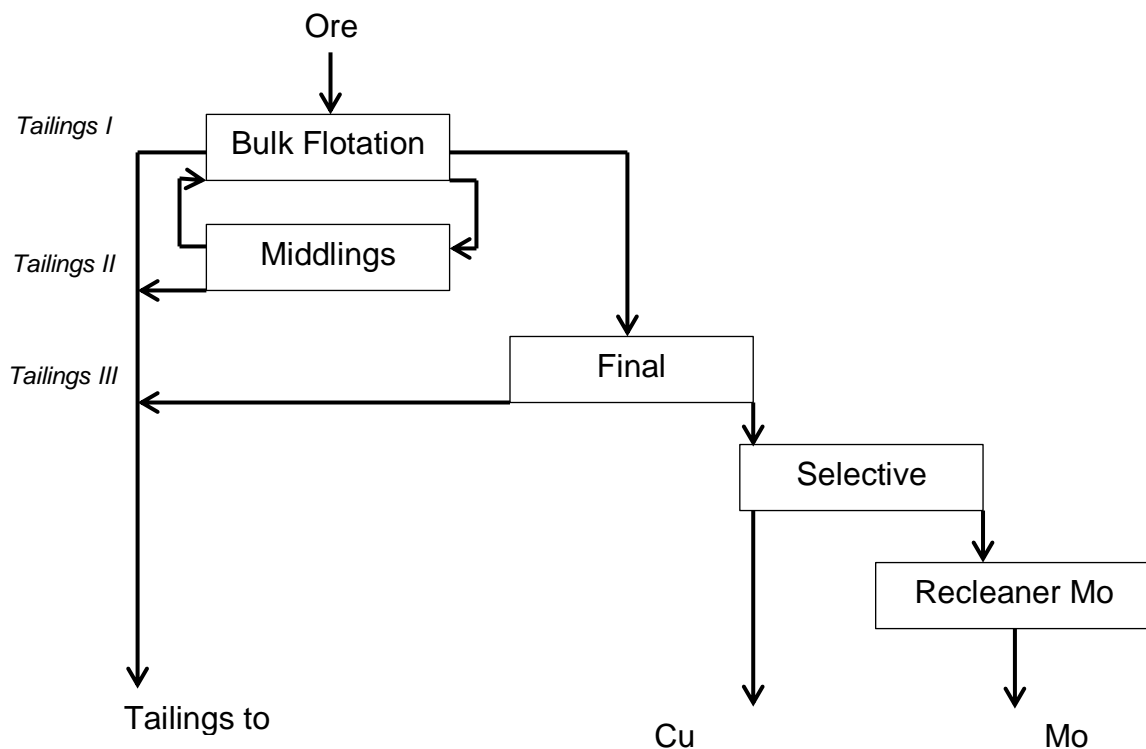
2 State of art

2.1 Erdenet Processing Plant

Erdenet is one of the world's largest mining and processing sites with an annual production of 530,000 tonnes of copper and 4,500 tonnes of molybdenum concentrates. The Erdenet Mine Corporation is located 340 km far from Ulaanbaatar, 140 km far from the Russian borderline, and started its operation in 1978 based on the agreement between the Mongolian government and (former) the Soviet Union.

The Erdenet Mining Plant flowsheet is complex with a two-phase Cu-Mo ore dressing process. The process operates three sequential stages of bulk copper and molybdenum concentration, where Cu content 15-17% and Mo content 0.4-0.5% settled, final concentration circuit, where Cu-Mo concentrate with Cu content of 23.5%(optimal value) from copper selective flotation and Mo content of not less than 47% for the quality of the product of Recleaner Mo flotation. The final copper concentrate is obtained as Rougher Molybdenum flotation middling product. (Yu. P. Nazarov, 2015)

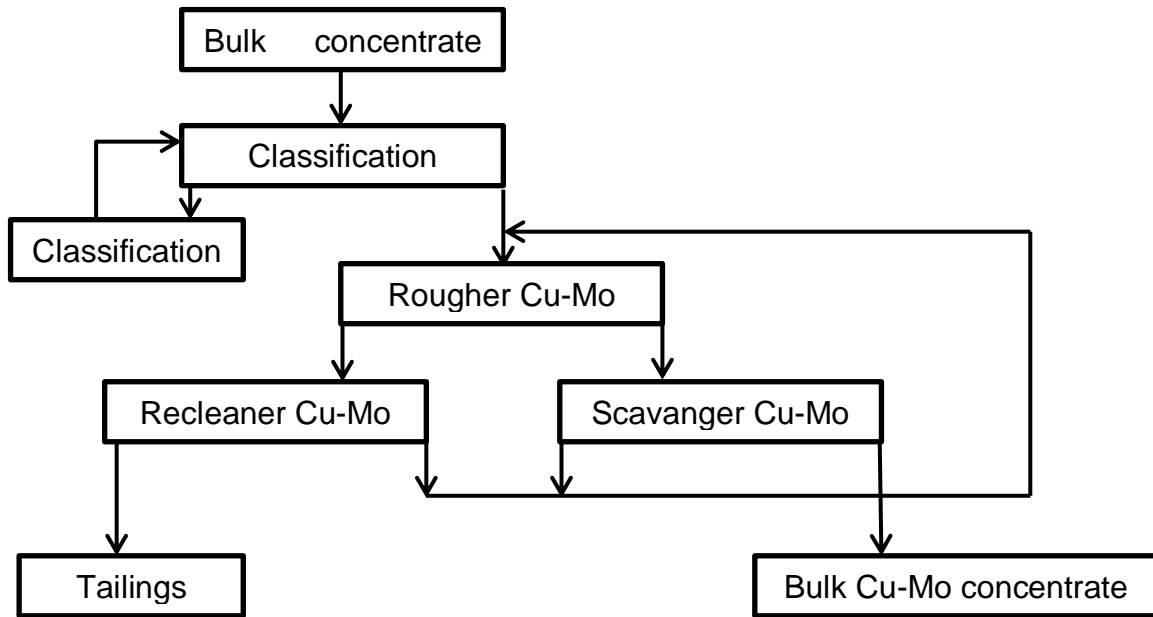
Figure 2-1: Flowsheet of tailing destination



Tailings I(Recleaner bulk flotation tailings), *Tailings II*(middling cycle tailings), *Tailings III*(Cu-Mo flotation tailings)

The final concentration circuit is the stage where bulk concentration is washed and thickening. The discharge of thickener is fed into mill MSH-CHTS-3200x4500 in a closed circuit with two cyclones GTS-500 then introduced to Cu-Mo flotation. (Nazarov, 2015) The output of thickener is composited in bulk concentrates which received from the total number of six circuits and the discharge is a feed of the final concentration circuit in terms of Erdenet Processing Plant Copper-Molybdenum flotation.

Figure 2-2: Basic flowsheet of flotation unit



The Erdenet Concentration plant is a production unit with crushing, grinding, flotation, filtration drying, and shipment of the copper and molybdenum concentrates. The production has 2 technological mainline, the first line has an annual production of 20.5 million tonnes of ore and line of crusher and 2 stage grinding mills. The second line has 5 million tones of annual production and uses the autogenic grinding section. An upgrading process of Erdenet consists of rougher flotation, a recleaner flotation, and a scavenger flotation then produces high metal contents in the final product required for successful commercialization. The prepared ore slurry passes through flotation plants of different types in several successively arranged circuits. The concentrate resulting from the scavenger flotation represents the final product of a flotation cycle and is removed from the circulation. The recleaner tailings produced by the recleaner flotation process represent the waste product and are also removed from the circulation. The remaining flotation products (recleaner tailings, scavenger concentrate) are used together with the starting mixture to feed the rougher flotation (middlings). The first stage of the flotation process is the bulk flotation cycle initially charged with slurry ore as a preparatory cycle. The product bulk concentrate of the first

flotation cycle is fed to the main flotation cycle (Cu-Mo flotation), in which the concentration of the scavenger flotation, the copper content of around 23.5% and molybdenum content of 0.4-0.5% is achieved. This concentrate is marketable as copper concentrate. The final product from the scavenger flotation is a bulk concentrate with copper contents of 15-17% and molybdenum contents of 0.4-0.5%. The tailings are from recleaner bulk flotation cycle, additional middling flotation, and recleaner scavenger tailing. Using an additional selective flotation cycle, marketable molybdenum concentrate is recovered. The concentrate from the main cycle is used as the starting mixture (middlings). Molybdenum concentrate with Mo contents of not less than 47% is taken from the recleaner flotation of the selective molybdenum flotation. The middlings is recirculated so that no new tailings generated for disposal in the selective molybdenum flotation. For the current situation, flotation circuits do not involve with other mixtures such as deposited tailings even after preparation or as an admixture in small proportion. This would cause at least uncertainty to the target for metal concentration in the final product.

Molybdenum concentrate. The bulk concentrate is mainly in the form of free flakes and grains. There are aggregates of molybdenum with chalcopyrite, non-metals, and pyrite. Chalcopyrite mainly occurs as free grains mostly -10 μ m

Copper concentrate. The product contains 42% nonmetals. A considerable proportion of chalcopyrite occurs as crushed aggregates with nonmetals and as mixed and uncrushed aggregates with pyrite.” (Yu. P. Nazarov, 2015) The research project conducted on the Erdenet PP Tailings sample. The results are directly derived from the paper and will be discussed in comparison to our project laboratory result.

2.2 Tailing dam description

Tailing Storage Facility TSF has 18.6 km², 27million cubic meters water volume, and 718 million cubic meters of solid volume. (Aslan, 2019) Process plant tailings have three destination recleaner bulk flotation tailings, middling cycle tailings, and Cu-Mo flotation tailings. Plant tailings transported with pipe to tailing storage tank, with a dimension of length 9m, wide 6m, and height 13 m and total volume of 700 cubic meters. Tailing storage tank is located at 1305m above the sea level, has 3 pipes, with the dimension of diameter 1.2 m and around 4.5 km long, to transport waste slurry to the tailing dam by gravitational force. The level of the suction pump is 1253m and the total head loss of 52 m results in a 25-30 m pressure drop at the inlet of the suction pump. Then the slurry is dumped according to 4 lines of pressure pipe, old right (diameter of 1.2m and 2.6 km long), old left (diameter of 1.2m and 2.9 km long), new right (diameter of 1.24m and 2.9 km long), and new left (diameter of 1.4m and 8.4 km

long). From 2023 to the 2031 year TSF was planned to have a feed flow rate of 35 million tons per year and 14800 m³/h flow rate.

The initial height of the tailing dam was 15m now the height of the tailing dam is 102 meters and 3.2 km long. The total dry sand area of the tailings dam is around 1380 square meters and total water-like surface area 462.3 square meters at the end of 2017. Due to the annual production of 35 million tons, tailing pond level increases by about 1.8 meters each year.

Figure 2-3: Tailing dam design (Aslan, 2019)

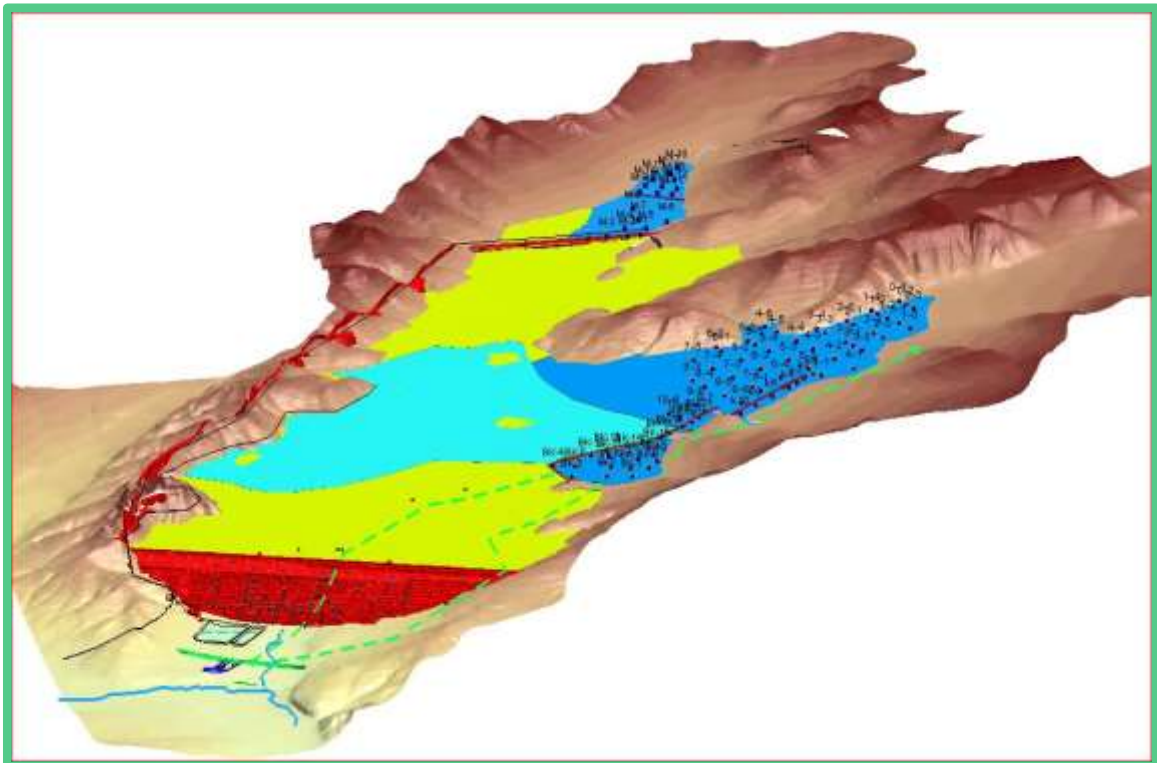
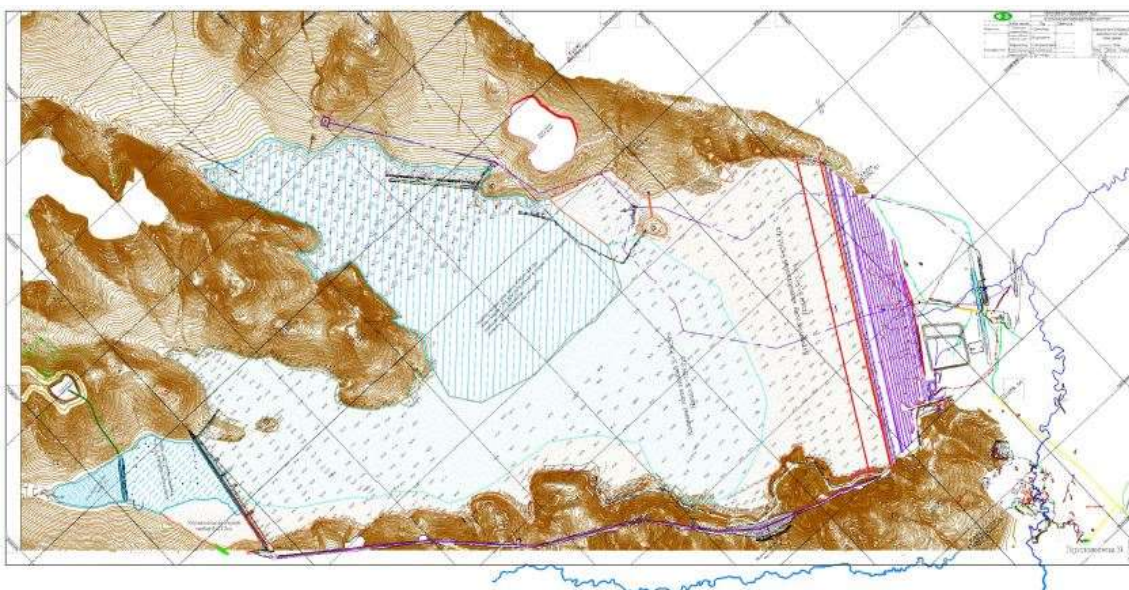


Figure 2-4: Tailing dam scale 1:1000 (Aslan, 2019)



2.3 Tailing description

The treatment residues are dumped in a tailings facility with a total area of 18.6 km², a water volume of 27 million cubic meters, and currently the volume of a solid of 718 million cubic meters. (Aslan, 2019) The tailings have possibly high copper and molybdenum content, therefore, some of them are technically possible to treat tailings material together with the ore in the treatment process and thus significantly increase the overall yield, which can lead to an increase in resource efficiency and a reduction in the demand for land area and water while maintaining production.

Erdenet Mine tailings are collected within three destinations; recleaner bulk flotation tailings, middling cycle tailings, and Cu-Mo flotation tailings. The final concentration tailing, which is tailings III, has comparably higher 0.2-0.5% of Copper content and 0.1-0.2% molybdenum content. The means of higher Cu-Mo content do not cause of poor process circuit but is related to feed content of the process. The worldwide copper concentration for the primary source of metallurgical plant is standardized at the range of 20- 25%. Erdenet Processing plant production meets the need and can exceed the marketable concentrate content.

As for high Molybdenum content in tailings is preferable to get needed copper concentration. In other words to get final results of copper concentration the flotation environment has to be a lime environment with CaO content 400-500mg/l in the rougher concentration and up to 700 mg/l in a scavenger flotation cell. This condition leads to a depressive attitude for molybdenum and we cannot withdraw the result. (Nazarov, 2015)

Tailings composition

Cu-Mo Flotation tailings have chemical composition $f_{(%)}$:

The research was aimed to reprocessing tailings III so that the following findings will only apply to tailings III.

Cu- 0.2-0.5, Mo 0.1-0.2, Fe_{total} 25-35, S_{total} 28-35, S_{sulf} 31.9, SiO_2 20-30, Al_2O_3 5-8, K_2O 1.5, Na_2O 0.4-0.8. (Yu. P. Nazarov, 2015)

The tailing has also had phase composition,% relatively: 4-6 oxidized; 40-45 secondary, 45-50 primary; 5-10 gray copper ore; 100 total. (Nazarov, 2015)

The analysis of dissociation ability of mineral particles in CMF Tailings has yielded as:

- Secondary copper sulfides are mainly represented by chalcocite and bornite,

- Copper and Molybdenum mainly occur in aggregates with nonmetals, and, partly, with pyrite;
- Content of free chalcopyrite grains is under 6%, free grains of secondary minerals of copper are absent; for both minerals, aggregates with barren rock prevail in mass—56 and 60%, respectively; up to 40% of chalcopyrite occur in relatively large aggregates — from –250 to –40 μm ;
- Molybdenite is almost in full dissociated; its loss in tailings is connected with the high content of CaO in process stages.

Although deposited tailings of the Erdenet settling pond may have possible metal contents of copper and molybdenum their processing is difficult. The tailings have a high diversity of metal contents which has to be found some trace elements and their chemical and physical properties vary differently because of ore content and the chemistry. (Nazarov, 2015)

2.4 Possible methods to reprocessing tailing

There are many possible ways to reusing tailings and methods differ in how much potential metal recovery can be obtained from tailings. Tailings contain residual valuable materials in some cases the production rate of processing primary ore can be higher if we taking an account that tailings are mined and processed beforehand.

As mentioned in (R.B, 2002) paper Mine tailings can be observed as the single largest source of copper in waste deposits in the US copper cycle and (Johansson, 2013) categorized tailings as valuable stocks of metals in the “technosphere”, indicating that reprocessing could also be an innovative reclamation technology.

In 1994, 2% of the total worldwide copper production came from reprocessed tailings. (K, 1982)

Reprocessing the tailings is considered an environmentally and economically effective technique to prevent Acid Mine Drainage (AMD) problems for either old mines or new beginning mine. Some old mines have never treated AMD production, result in the contamination of both surface and subsurface waters and serious degradation of surroundings.

If we can reprocess tailings and reduce hazardous residues in tailings, that would be a possible way to save either money (for taxes) or the environment. But the feasibility study should be carried out whether reprocessing can be profitable than just dumping. There are many potential ways to reprocessing tailings but critical aspect of the reprocessing is profitability.

2.4.1 An admixture of current flotation stream

Mixing up deposited tailing with a current stream in the flotation circuit may increase the application yield but it would decrease the quality of the product while Erdenet Concentration plant has been achieving great success with the high yield of Cu and Mo concentrates. It would result in a bad reputation for the current achievement of EMC. So that the processing of the deposited tailing using ore optimized process step is difficult. A challenge would be set to use tailings to current stream but the final metal content has to reach 25% of copper. Therefore, an admixture in the existing circuit would be limited. In the current study, from fresh tailings of the main flotation cycle in the ore treatment of Erdenet could be recovered in the experiment, a Mo concentrates with about 45% Mo at a recovery of 66%. The copper concentrate produced had a Cu content of about 15%, the recovery was 52%. (Yu. P. Nazarov, 2015)

But the study says that copper sulfide minerals are finely disseminated intergrown with pyrite and associated or occluded with gangue minerals reprocessing may not be feasible due to the high costs involved in both separation and liberation. (J.Alcalde, 2018)

And another study (Michael J.Mankosa) referred that coarse and fine particles are considered more difficult than intermediate size particles in regard of floatability. The proof study was held with a high number of investigations. The Flotation response of copper ore as a function of particle size using conventional flotation techniques has its maximum value where particle size ranges between 30 and 150 μ m, considered the result differs depending on the ore processing.

For finer particles, lower recovery is typically attributed to low bubble-particle collision rates that reduce the probability of attachment. Low collision rates for finer particles can generally be overcome by utilizing the equipment that improves the flotation rate. Flotation rate can be increased as the total surface area by either reducing bubble diameter size or increasing gas flow rate. Indeed with small bubble generations, recovery can yet be challenging as longer the retention times are typically required for finer particles. Further, as plant and equipment continue to grow in size, many of the capital savings achieved by utilizing fewer cells are lost due to inefficient mixing intensity. (Michael J.Mankosa)

Metal recovery from tailings has main parameters that affecting recovery: the particle size of tailings, and the nature of the metal-bearing minerals, the behavior of the froth during flotation, and the age of tailings. (Abdelkrim Nadeif, 2019)

2.4.2 Leaching

Leaching is a process that involves a two-phase system and absorption techniques. The leaching of minerals often in the solid-liquid phase, where the solid (minerals) suspended in liquid medium (leaching solution) for a certain time (leaching time). Or heap leaching, which is very often used because it does not require a big plant to leach the minerals, it can be in the site where the dumped materials and the leaching solution is sprayed on the top of the heap and penetrates through the particles while getting the valuable materials selectively. But this method favors more big particles than fine ones due to penetration efficiency, where the fine particles can not let the solution go through them.

In the last decade new ways of processing tailings, the most popular option is bioleaching which is a very effective also environmentally friendly and best way to combine environmental management and metal recovery. From some views it may be difficult to have bioleaching in Mongolia, in-situ bioleaching is preferable for mine tailing dam but to keep the efficiency of bioleaching the leaching environment has to be favorable for chosen bacteria but to keep the temperature is hard for extreme weather.

A representative methodology for leaching process is shown in the paper (Janine Figueiredo, 2018) and the characteristics of tailing were, the chemical composition of Cu 4738 ppm content, Fe 23.8% of weight, Zinc content of 9.9944 % of weight sample were processed with a total mass of 0.1667 kg in 0.5L reactor with 80 degrees of celsius hot. The leaching solution was prepared with sulfuric acid and ferric sulfate (0.5M) for 6 hours. And the recovery of the whole process was 43.4 %.

2.4.3 Construction material process

The oldest yet a good way to reusing the tailing is putting to use in products such as ceramics and other construction materials. Especially copper mine tailings often used for construction material because the tailing have some valuable remedies such as copper, gold, silver and most importantly rare earth elements, which is proven that can affect the quality of building material. Possible products, which are made with copper mine tailings, bricks for construction, road base material, and ceramics.

A good example of building material, the copper mine tailing was used for making alternative road base construction material, where the mine tailing was mixed with a specified amount (0-11M) of sodium hydroxide solution then, rested for 7 days at 35 degrees of celsius. After making the specimens, some analyses were done on

specimens such as microscopy, energy-dispersive X-ray spectroscopy, etc. (Manjarrez, 2018)

2.4.4 Pyrite recovery

If we considering the main aspect of the project is to reduce their environmental impact, the desulfurization of tailings and pyrite recovery process are potential techniques.

AMD causes so much trouble like safety regards to tailings dam failures, air pollution like EMC white dust generation, and water pollution. Desulfurization is best for preventing AMD in mine areas yet the method requires a flotation method, which means we have to build up a new flotation circuit to add current process flow. In the study desulfurization of the old tailing which contains Au (3.36-5 ppm), Ag (24-37ppm), and Cu (600-800ppm), flotation processes were done to get these metals recovered from tailing and the recovery of each metal was obtained, recovery of sulfide around 75%, recovery of gold weight-yield was 3-4.5%. for sulfide recovery, copper sulfate solution was added to activate sulfide, and the collector was amyl xanthate with a dosage of 50 g/t. Desulfurization test was performed with sulfide bulk flotation and the sulfide-bearing minerals have high recovery at a max 73%. So it is preferable for operating mines and new mine projects. The resulting desulfurized product can be treated separately or backfilled underground mines. (Abdelkrim Nadeif, 2019)

With the subsequent pyrite flotation, a pyrite concentration of 98% pyrite could be achieved, with 89% of the pyrite could be recovered from the tailings. In addition to the significantly reduced pyrite content, the copper content in the tailings was reduced to 0.13% and the molybdenum content to 0.09%. Besides, the objectives are also intended to Mongolia, especially to the Erdenet Group, to reduce environmental pollution and to generate natural resources intelligently and protectively. This can also contribute to secure, clean, and affordable energy and raw material supply.

3 Methodology

3.1 Onion methodology for data collection

Onion methodology is used for structural and compiled data collection. During completing each level of the methodology, research data collection would be more and more structured that the data and information are collected under an umbrella, then comparison and contrast can be done within the frame of work. Through research methodology, data and information are drawn from the different sources and identified with their similarities and contrary to ready for analysis.

In the introduction section, the methodology I have chosen, and at each layer what was my approach was written in detail. The General concept of methodology aims at a quantitative approach where data and information collected based on hypothesis, which was estimated with literature review, then expanding pattern of data range with data collection and analyzed or summarized to build the theory of our chosen case.

3.1.1 Arguments

Arguments were formulated within the objective of the research. The main research question was: What method is proven efficiently to reprocess copper mine tailing?

The arguments should answer the research question and to answer the question secondary data, with the experienced author or from a reliable and competitive data source, collected, is known as a literature review. Based on the literature review, a tentative hypothesis is developed for further data collection

3.1.2 Hypothesis

Hypothesis 1: Reprocessing tailings with current process flow, selective flotation, is efficient and reaches 60% recovery.

Hypothesis 2: To reduce the environmental impact of tailings, pyrite in tailings should be recovered and the selected method is pyrite flotation.

Hypothesis 3: The simplest method to reuse tailings is making construction material.

3.1.3 A quantitative approach for data collection

As for quantitative analysis, data and charts or graphs are suitable for comparison and contrast. Data collection was made under the research objective within the fringe that was built during methodology. That can help to keep the right track and to be efficient during data collection. In our case, not only numeric data but also qualitative data such as papers or patents that can introduce the whole image of the

processes should be collected. To be able to compare or combine that information with a different basis, every source of information has to be criticized.

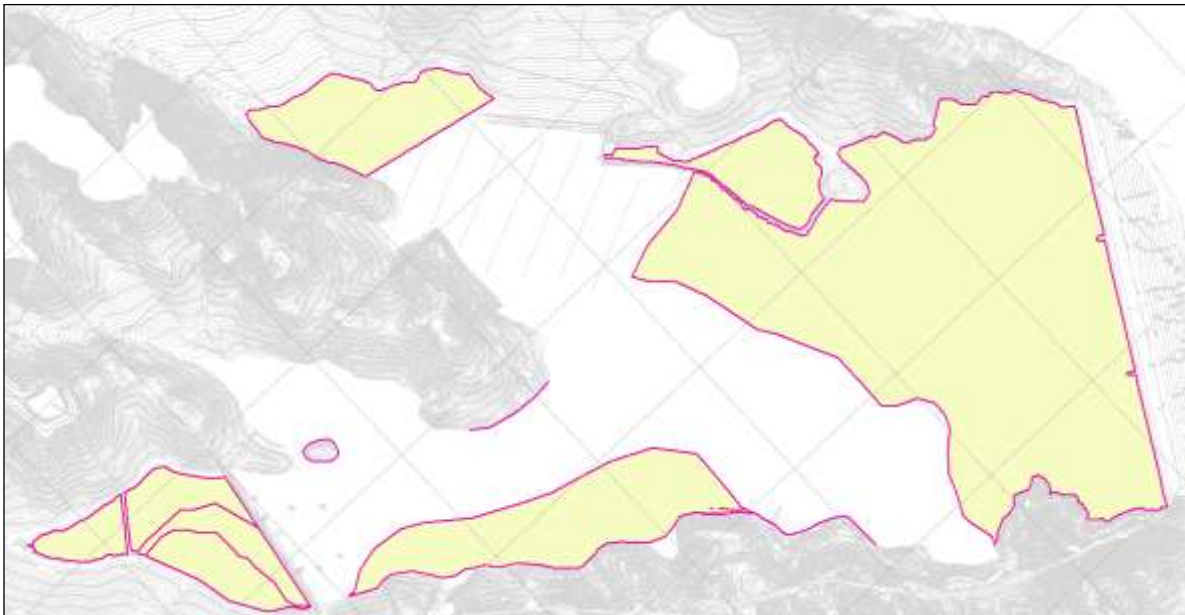
Sequentially the procedure of data analysis has to be clear and realistic. The result of the analysis should be predicted roughly.

3.2 Materials

Materials, that used for data analysis, were derived from EMC TSF. To collect samples that can represent whole tailings characteristics, sampling points were chosen randomly but the tailings itself has over 40 years history, and perfect representative samples can not be obtained by bulk sampling method.

The tailings pond was divided into sub-areas where the samples can be taken. The coordinate grid is drawn on the geological map.

Figure 3-1: Coordinate grid different areas of tailing pond



3.2.1 Sampling

3.2.1.1 First sampling

Tailings samples were taken at 20 drilling points P-1 to P-20 at the end of 2017. The study was conducted by EMC and analyzed in CGL. The drilling depth was 10cm and the samples were geochemically analyzed to determine the component chemical analysis. The contents of the following elements were estimated at each sample: Ag, Al, As, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, K, La, Li, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Sc, Sn, Sr, Ti, V, W, Y, Zn, Zr.

Figure 3-2: Location of sampling points of tailing pond



3.2.1.2 Second sampling

Samples were collected from 5 different areas of the tailings dam. Compared to first sampling the depth of bulk sampling differs. The samples were taken from the depth of 10cm, 20cm, or 40cm at several sampling points and 42 samples were collected, which differ from each other as their sampling point and depth.

The sampling points were near to the dry sand area of the tailing dam because it is difficult to take samples from the center of the tailing dam and might some additional equipment would be needed. The exact location of the second sampling area is undetermined.

For the particle size analysis and wet screen analysis, only one sample was chosen randomly but for precision sake, the sample was analyzed with parallel 3 analysis. The result was written as the mean value of the three results.

3.3 Analytical methods

Analytical methods were used to determine the physical and chemical characteristics of the samples. These methods are screen analysis and XRF (X-ray fluorescence) analyzer.

The particle size analysis was dedicated to defining the physical characteristics of the sample and the significance of the analysis is particle size distribution along with the size ranges. Otherwise, elemental analysis can show how the elements or components can compose the tailings. I could investigate how the elements distributed along with the particle size ranges.

3.3.1 The choice of methods

3.3.1.1 Particle size distribution measurement techniques

The particle size analysis can be done by many methods or techniques, mostly:

- Screen analysis
- Sedimentation methods
- Microscopic sizing and Image Analysis
- Laser diffraction method

The most common method is screen analysis since it can be used on a laboratory scale easily, done with a wet sieving or dry sieving method, and the performance of the process can be affected by the amount of sample put on the sieve and the motion of materials through the sieve hole. The equipment used for this method is sieve shaker, which has designed with a dynamic power source to confirm the suitable vibration to the sieve and sample, in case of wet sieving the flow amount of water also plays a big role. This type of method is approved for bulk material (heavy samples) without loss of performance and provided separated size fraction for the next analysis.

The second method sedimentation is established on analyzing the settling of the sample particles and observation of the even distribution in the liquid medium. The method is known as beaker decantation and the equipment that is used, is the syphon tube, where we can easily see the settlement of particles and measure the height of settled particles and water, and settling time. This method is claimed to have true fractional size analysis results and overcome other analyzing methods, but a long time is needed to complete settlement for fine particles like ours. Moreover, an additional test has to be done to separate the particles with size fractions.

Microscopic sizing is an outright method for size distribution because it involves each particle and observation and analysis would be done in a microscope. The result is an image that is two dimensional and from that the particle size can be measured, the measurement size range can be between 0.8 and 150 microns. The method is a good choice for a small portion of the sample is taken, and a very fast measurement technique. To improve the performance of the measurement more developed types of equipment such as electron microscope and automatic measurement devices are needed.

The principle of laser diffraction method is, the laser goes through the medium where the particles suspended diluent and circulate through the optical cell. The light is scattered by the particles, then detected by a solid-state detector, where the light

intensity over the range of angles is measured. The principle of scattering light distribution pattern is a measurement for the particle size distribution, where the fine particles cause more scattered pattern than coarse particles. The result is in form of graphical representation, often histogram, shows the frequency distribution, represents the percentage of particles found, vs size ranges, particle diameter in microns.

Among these methods, the analyses were done by the wet screen method, which was the only available method to perform at that time. I assume that the laser diffraction method was the most suitable for our case since it is more precise without error, and the particle size was fine. But the wet screen analysis was done successfully and we are discussing that in the next section.

3.3.1.2 *Elemental analysis measurement techniques*

Common analytical techniques used for elemental analysis are Atomic Absorption Spectrometry, Flame atomic absorption spectrometer, and X-ray Fluorescence. (Helaluddin, 2016)

Atomic spectroscopy is involved in atomic absorption, emission, and fluorescence. Every element has a certain amount of electrons which is moving around the nucleus and the atomic spectroscopy generally deals with the outer electrons. There are 2 main states that an atom can be, a ground state is the most stable electron configuration, and an excited state is when the outer electron is promoted to a less stable orbital configuration by a certain amount of energy. When an outer electron absorbs a portion of energy with a specified wavelength, the electron is elevated to an excited state from the ground state and releases light. then the detector detects the wavelength of the released energy and defines the element. Atomic Absorption spectrometry can determine about 70 elements and it can measure the content of the elements which is quantitative information and what elements are present in the sample which is qualitative information.

Flame atomic absorption spectrometer (FAAS) is a chosen method for low quantity concentration metals in a given sample and the precision is very high at ppm. The typical types of FAAS are air-acetylene and nitrous oxide flame atomizer. The principle of the equipment is very similar to an atomic absorption method but the sample is introduced into atomizer as an aerosol, which is enclosed under pressure and released as a fine spray by nebulizer. The method is so fast as 10-15 seconds per sample and mostly heavy metals, Cu, Fe, Pb, Cd, nickel, Cr, Mn, and Zn, in a sample. But to prepare the sample which can be evaluated by this method, additional experiments have to be done by soluting the solid sample in the aqueous media. For

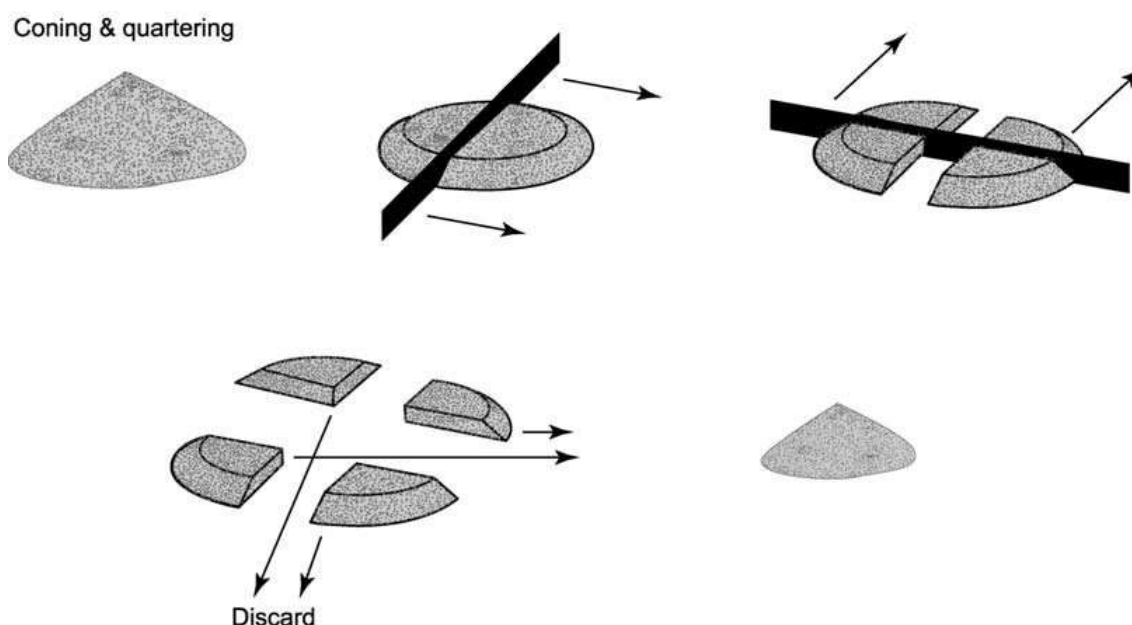
example, an Aqua regia is, often used to dissolve noble metals like gold and platinum, a mixture of nitric acid and hydrochloric acid with a molar ratio of 1:3.

X-ray fluorescence (XRF) involves X-ray as can be seen from its name. When high-intensity X-ray radiation hits an atom, it forces out some of the electrons from inner orbitals, and the atom promoted to excited state. The outer shell electrons fill the gap, whose energy is lower than initial ones so that energy would be released in the form of X-ray. It is a very easy method that can be used in both laboratory and in-field analysis. And the measurement range is wide and the sample should not have to be great in amount. But the important point is sample preparation, which can be representative and reliable.

Among these methods, the XRF method was chosen to analyze our sample and it was more suitable than other methods. Because it is easy and there is no need to dissolve the sample in aqueous media and was available in GMIT Processing laboratory.

The preparation of the sample was done with a coning and quartering method because the sample amount was too little for other methods. First, the sample is poured and make a conical shape then flattened it out into cake. The cake divided into quarters the two opposite quarters discarded and remained quarters combined and make conical shape again. This process would be repeated until the proper amount of sample remains. This method is known as the best and easiest sub-sampling method to reduce the sample amount without making a systematic error during the process.

Figure 3-3: Coning and Quartering procedure (Robert, 2011)



3.3.2 Wet screen analysis

Wet screen analysis is used to evaluate particle size distribution of fine grains, the sample is suspended in a liquid medium. An Aqueous solution is used for negotiating static charges and break the aggregates down into same sized particles.

Before the screen analysis, sample preparation could be done to get reliable results. The sample was dry before dissolving it in water, the dry weight of the sample was taken then some water was added to get 35% solid density slurry. After adding the exact water, the slurry was stirred until the slurry was homogeneous. Then wet screen analysis was done for 15 minutes with an amplitude of 65 rpm on horizontal sieve shaker.

The sieve sizes used in the sample of 2017 are 500, 250, 125, 50, and 25 microns.

The sieve sizes used in the sample of 2019 are 210, 149, 105, 74, and 44 microns.

After a wet screening, each sample on the sieves was collected and dried in a laboratory drying oven. If the drying process was completed then each sample within the size range is weighted.

While analyzing data and setting the distribution curve, the terminology of a number basis and volume basis can show up. The number basis means that particles are distributed along with the size range and are directly related to the number of particles on the sieves. In another word, assumes each particle has equal mass weighting and very evenly ground where no abnormal sized particle is obtained.

Volume basis means the big particle occupies more volume than fine particles, can be said that big particle with 10 cm diameter occupies as same space as one million particles with one-micron diameter. On volume basis distribution, the coarse particle volume may dominate fine particle normal distribution and defects the distribution curvature.

3.3.3 XRF analysis

XRF analysis is a process where electrons are displaced from their atomic orbital positions and releasing energy that can characterize specific elements. The release of energy is detected at the XRF and the analyzer turns the energy as specific elements. The entire process occurs within seconds. Sample preparation and sample homogenization should be done before the XRF analysis to maximize boost precision.

Before XRF analysis began, the analyzer has to be warmed up for 150 seconds, the standards have to be tested to calibrate the analyzer. Samples were placed in sample cups and analyzed with the instrument in „Mining Cu/Zn“ mode, the time set to

30 seconds. The sample cups and 12.7-micrometer thick plastic wrap were used to hold samples.

During the analysis avoid direct sunlight and ensure to hold analyzer perpendicular to the sample cup surface. After each analysis, the sample cup has to be cleaned to ensure the purity of the sample.

The XRF analyzer has a detection limit and if the analytical sample has exceeded a detection upper limit or lower limit, the amount of element cannot be shown instead the analyzer shows LOD (Limit of Detection) where the range is from 0.1 to 0.7 $\mu\text{g/g}$. If the amount of component is too low and exceeds the lower limit, an analyzer shows <LOD, otherwise if the amount is too high exceeds the upper limit, an analyzer shows >LOD.

Another sign that the analyzer can show is Bal, which stands for balance and represents X-ray energy levels that the analyzer does not attribute to a particular element.

3.4 Method to compare and contrast the research papers

The analytic summary has to be made according to the reprocessing of EMC TSF tailing material and a suitable method to organize the findings had to be decided.

The first step is to identify the key concepts of these findings.

The second step is deciding the suitable method for organizing these findings.

There are generally two approaches to get the result and those are the Holistic approach, where the key concept of the findings are important, and the Head-to-head approach, where the key point of my thesis should be pointed out at first then the findings were matched to those points. I would like to combine these approaches.
(Walk)

The literature review section has to follow a holistic approach, by doing that the papers were roughly summarized then the key concept of each paper is examined. Then based on the analytical results of tailing characteristics and key concepts of the literature, the key point of the processing method is pointed out and analyzed.

Then comparison aspect of the methods would be built and following that path the choice of method is simply made.

4 Result and Discussion

4.1 Size distribution analysis

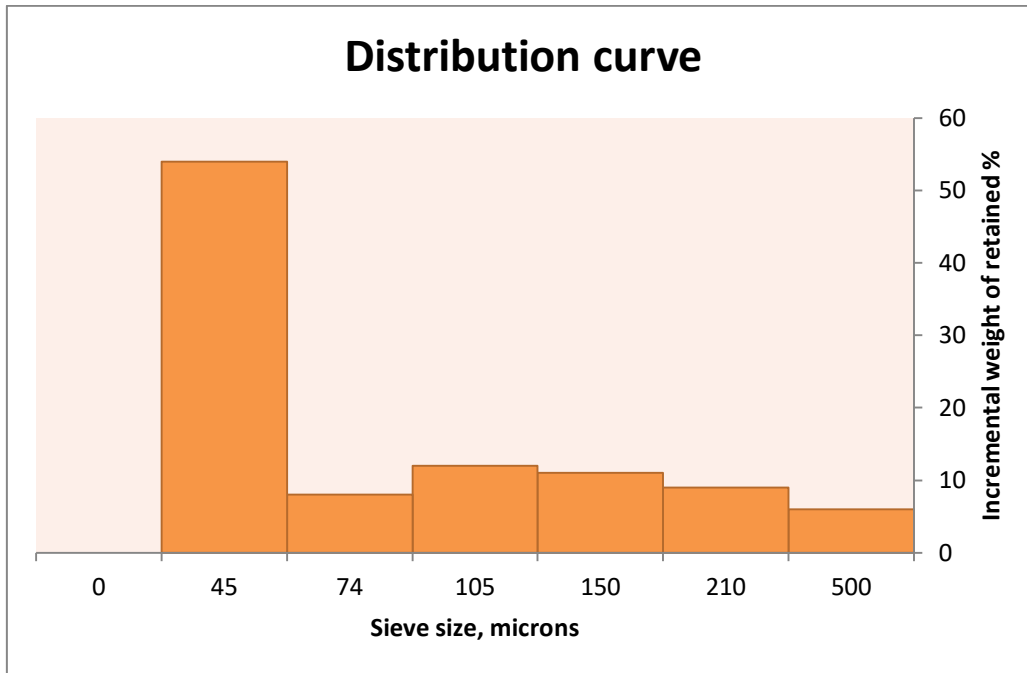
Tailing samples were taken in 2017 as well as in 2019. That allowed me to compare these samples and their characteristics within this period. The first sample that was taken in 2017, was analyzed in the Central Geological Laboratory, which is noted as sample 1. The second sample that was taken in 2019, was analyzed in GMIT Processing laboratory, which is noted as sample 2. As mentioned before the analytical methods which are used for elemental composition and size analysis, were done in both samples. The samples were done in different laboratories and used different methodologies so that the results differed in size ranges and compositions. The analyzers were also different so that the errors during the analyses could be caused by different reasons. For the analysis that was done in sample 2 by me, there could be more errors than sample 1 result since Central Geological Laboratory is far more experienced and probably they would be more accurate.

4.1.1 Result of particle size distribution analysis

Particle size distribution analysis shows how uniformly or unevenly distributed along with the size ranges. According to the literature review, the distribution of particles follows the normal distribution curve, and that results from good comminution. The normal distribution curve follows Gaussian distribution theory, Gaussian distribution is a bell-shaped curvature and assumption that during any experiment values, distribution curve follows a normal distribution with an equal number of measurements above and below mean values.

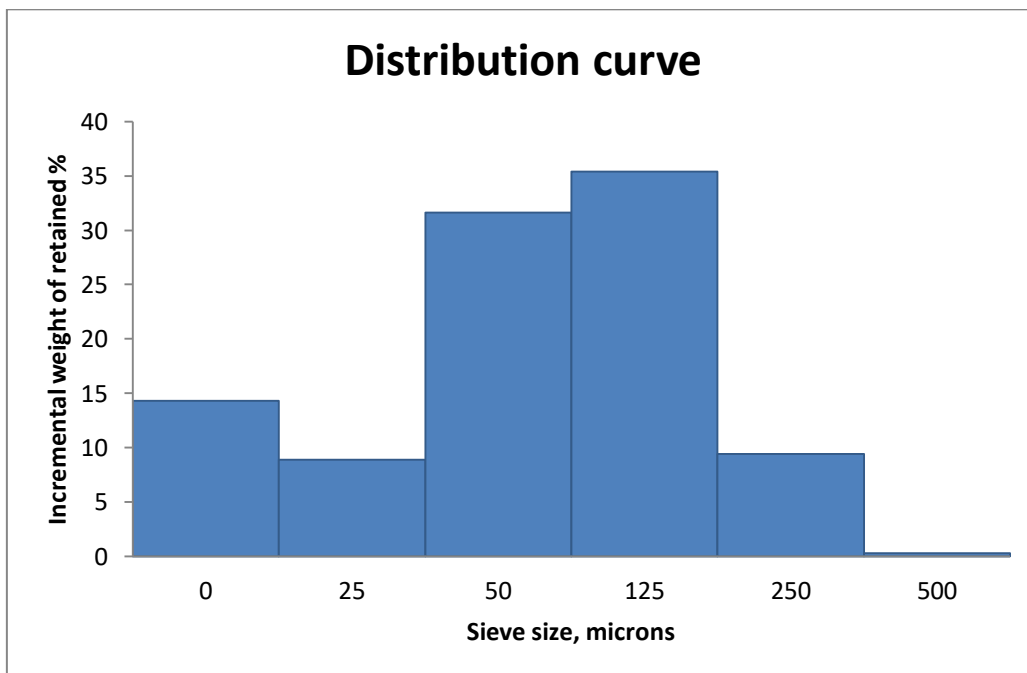
The first sample experimental result has not a bell-like shape which is not so good result. But the majority of volume obtained by mid-sized particles and if there was more sieve above 100-micron sieve and below 45-micron sieves in the analysis, the result would be more perfect. The huge rise of the incremental weight of percentage on 45-microns sieve, the more fine-sized sieves should be used to get more righteous particle size distribution along with size ranges. An abrupt end of distribution end does not mean the absence of particulate below or above the sieve size but mostly indicates the instrumental or technical errors during the process. Since the most of particle is obtained below the size of 74 microns is a good sign because the nominal grinding size of the regrinding mill in the process is 75 microns.

Figure 4-1: Distribution curve of sample 1 in 2017



The data used for plotting this chart (Table 1: Particle Size distribution analysis result sample 1)

Figure 4-2: Distribution curve of sample 2 in 2019



The data used for plotting this chart is in (Table 2: Particle Size distribution analysis result sample 2)

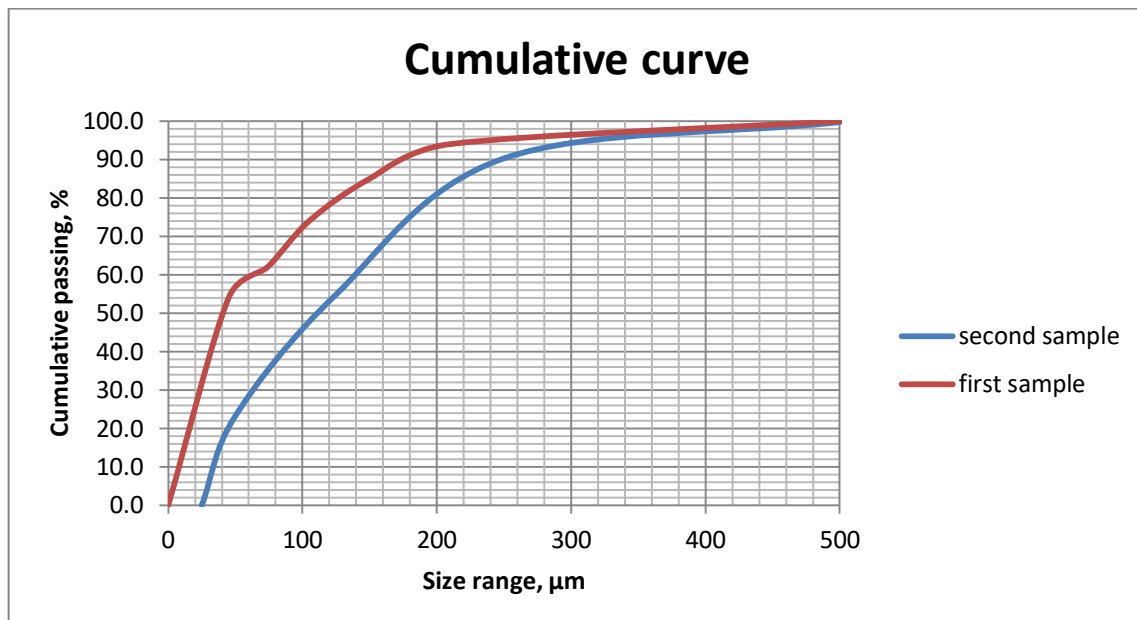
The second sample size analysis results in a good distribution curve but some defects observed in curvature because passing material at sieve size 25 micron was

greater than the above material. But the observation during the process can tell us that there were no abnormal sized particles, which means we have no volume basis distribution. Very fine particles were obtained below the sieve size of 25 microns and it weights more than the above size so that the curvature has a unique shape. The amplitude of the wet screening machine might have been too high or the flowrate of the water was too much and that may result in turbulent flow through the sieves and some particles were shattered because of that.

Besides that, the most volume of particles obtained at the mid-sized range, 70 microns to 125 microns, that concludes good distribution along with size range.

The data used for plotting the following diagram is in (Table 1: Particle size distribution data on sample 1), and (Table 2: Particle size distribution data sample 2).

Figure 4-3: Cumulative distribution curve of 2 samples and comparison



The data used for plotting this chart

The cumulative distribution curve shows at what size how much of the sample below that size and how much is above that. Cumulative curve of two samples, sample 1 was from 2017, and sample 2 was from 2019, were compared in below. The curvature of those curves is the same but if I consider the P80 size of those two there is a big difference. P80 is the screen size through which 80 percent of particles pass, P80 of the first sample is 110 microns where the P80 of the second sample is 200 microns. That is because the samples were analyzed in different sieve sizes and may the analyzer methodology was different.

4.1.2 Discussion of a particle size distribution

In conclusion, the particle size is evenly distributed and most of the particle is below 200 microns, which can show that the grinding process was very efficient. The reprocessing method should deal with these fine-grained particles. From the perspective of sampling, to prepare a more representative sample the sampling points had to be planned and at each sampling point, several samples should be taken from a different depth.

4.2 Result of elemental analysis

In this section, the result of elemental composition analysis would be discussed. This analysis method gives both qualitative and quantitative results. The qualitative result includes the presence of a particular element and what elements are present, the quantitative result includes how much of the particular element is present in the sample.

4.2.1 Result of elemental analysis on sample 1

The analysis was done on samples that were taken from 20 different points of tailing pond in 2017. In the result of the analysis, 9 elements were pointed out because of their high content and significance in tailing characteristics, which were Ca, K, Fe in %, Co, Cr, Cu, Mg, Mn, and Mo in ppm.

Some of the element content is shown below and the mean value of the elements from different points are:

Ca content has a mean value in %, 0.363 ± 0.0702 . Fe content has a mean value in %, 2.348 ± 0.3681 .

The data used for plotting Figure 4-4 to Figure 4-7, is (Table 3: Elemental analysis result sample 1).

Figure 4-4: Calcium content in sample 1

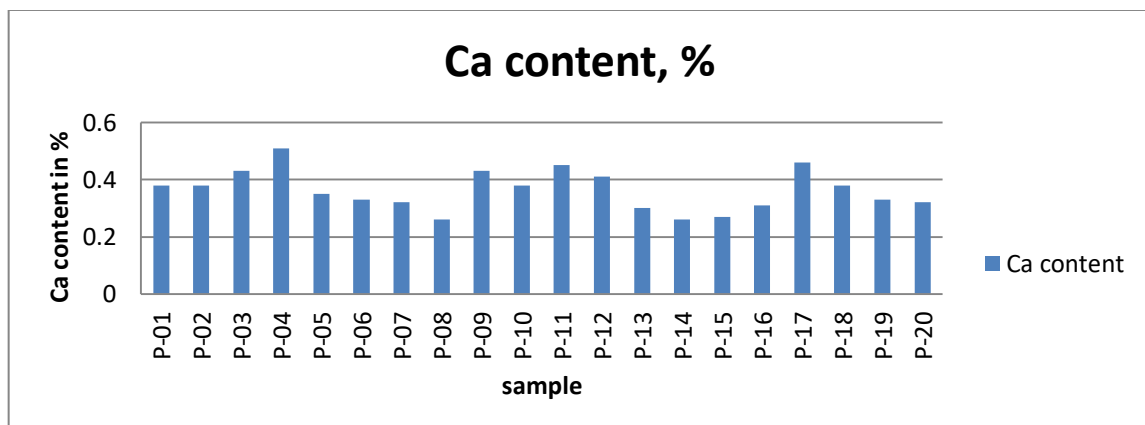


Figure 4-5: Iron content in sample 1

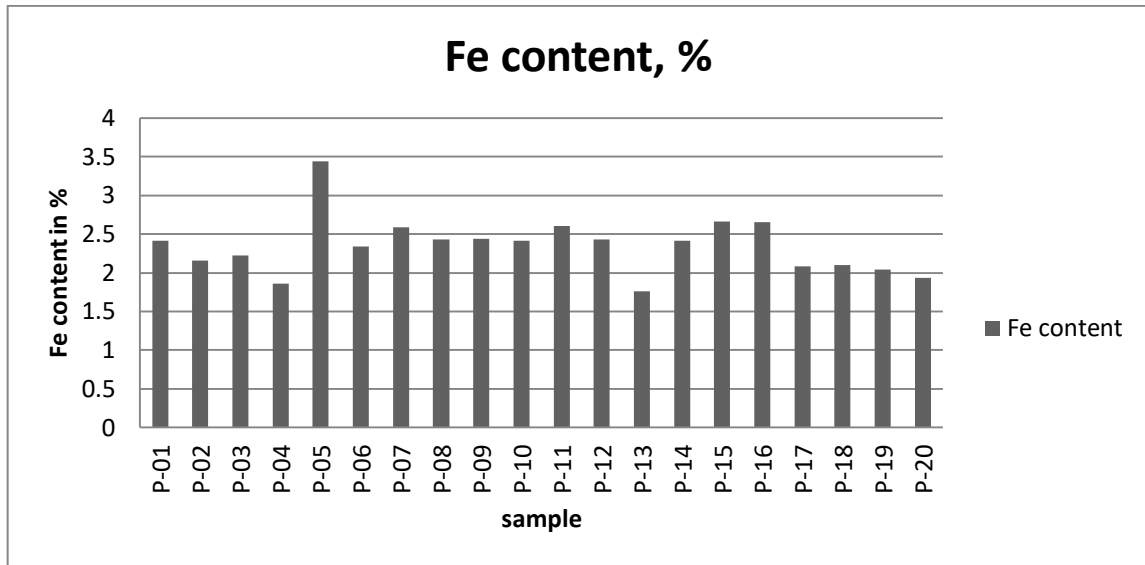


Figure 4-6: K content in sample 1

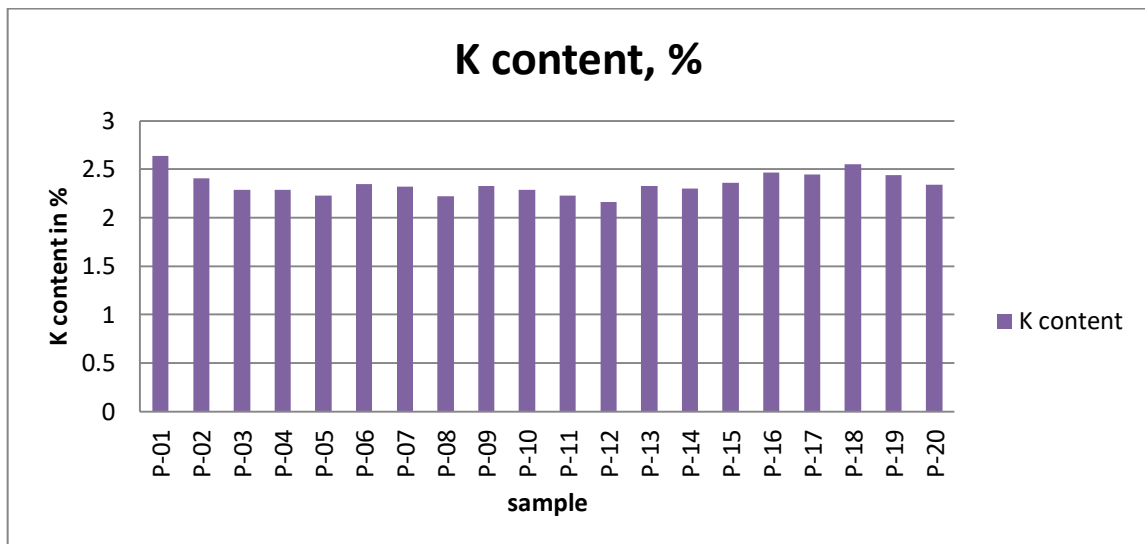
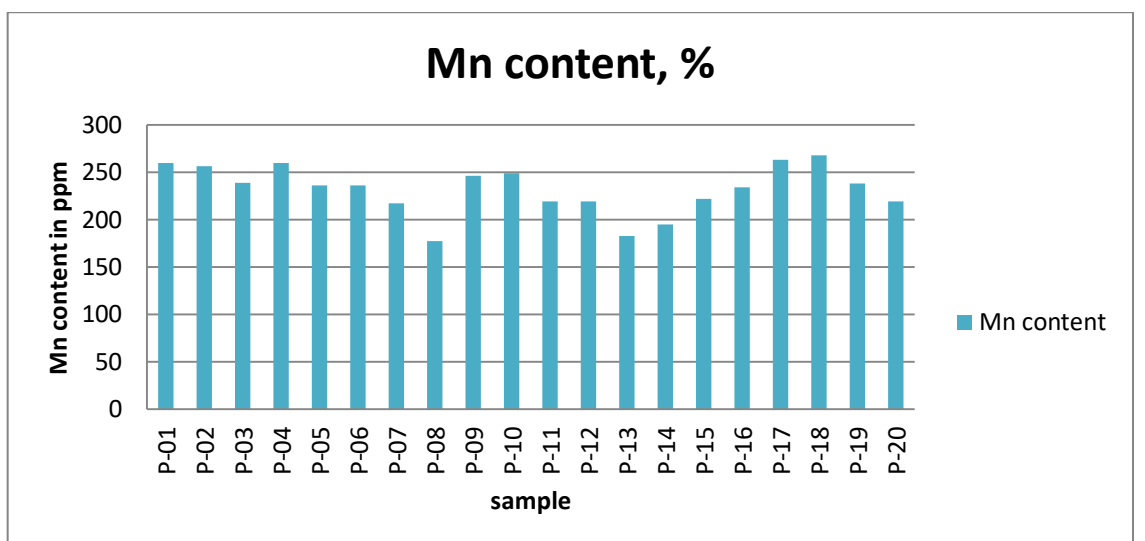


Figure 4-7: Mn content in sample 1



4.2.1.1 Discussion of elemental analysis

Based on the element contents, the sample values have not a too high deviation from the mean value, which encourages the reliability of the result. Some significance was observed that on sampling point of 5, contents of Copper Molybdenum, Iron, and Calcium were relatively higher than other sampling points. If I consider the location of the sampling point, P-015 was near to the discharging pipe position. I may estimate that the fresher the tailing the metal content is higher. Otherwise, the sampling point from P-14 to P-20 has not that high deviation from the mean value of elements and located far from tailing discharge location, where tailings have become already dry. Based on this information, I have observed that the longer settling time of solid in tailings is the heavy composition or particles in tailings would be settled to the bottom so that the dried surface layer has lower metal content compared to fresh tailing.

Moreover, the metal contents of elements in samples P-13 P-02 are significantly lower than the mean value, where the sampling point located randomly far from each other and near to other sampling points where the difference in metal content is not naturally high. So that another assumption was made that the sampling points and analytic results can not define the reliable history of the tailing. But if I did that assumption there is no point to writing thesis and the whole objective of my thesis would crumble to the end so I have hoped that there were some errors during the sampling or analysis or probably there are other possibilities that I have not recognized because of my lack of experience.

Figure 4-8: Sampling point of sample 1



4.2.2 Result of elemental analysis on sample 2

The analysis was done on samples that were taken from 5 different areas of tailing pond at where each area had several points were chosen and from each sampling point, samples were taken in different depths. In the result of the analysis, 34 elements were analyzed but 18 of them can not be detected because the content of the specified elements (Mo, Ba, Sb, Sn, Cd, Pd, Ag, Bi, As, Se, W, Ni, Co, Mn, Cr, V, P, and Mg) was lower than the lower detection limit of the apparatus.

The mean value of chosen elements, which have a high content in tailing samples and significant metals that may have possible reprocessing.

Calcium has mean value in %, 0.256 ± 0.03661 . Iron has mean value in %, 2.053 ± 0.11083 . Aluminum has mean value in %, 2.85 ± 0.4353 .

Copper has mean value in ppm, 580 ± 81.1 . Sulfur has mean value in %, 0.248 ± 0.0217 .

Chloride content was so high in mean %, 37.121 ± 1.1602 . and other balance Bal, that has energy level cannot attribute to a particular element, mean value of 45.826 ± 1.167 .

Then analysis result shows at which particle size range the specific element has what content value.

The data used for plotting Figure 4-9 to Figure 4-14, is (Table 4: Elemental analysis result sample 2)

Figure 4-9: Copper content vs size ranges of sample 2

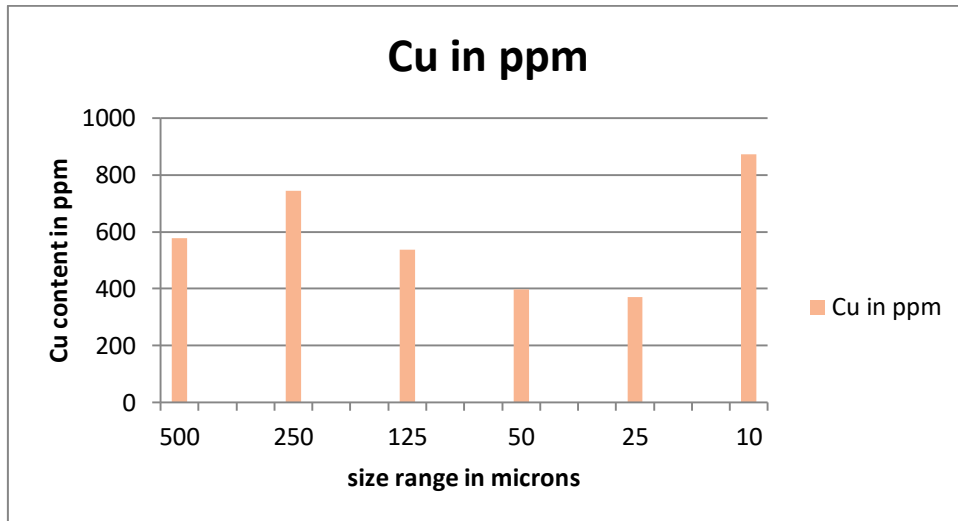


Figure 4-10: Iron content vs size range of sample 2

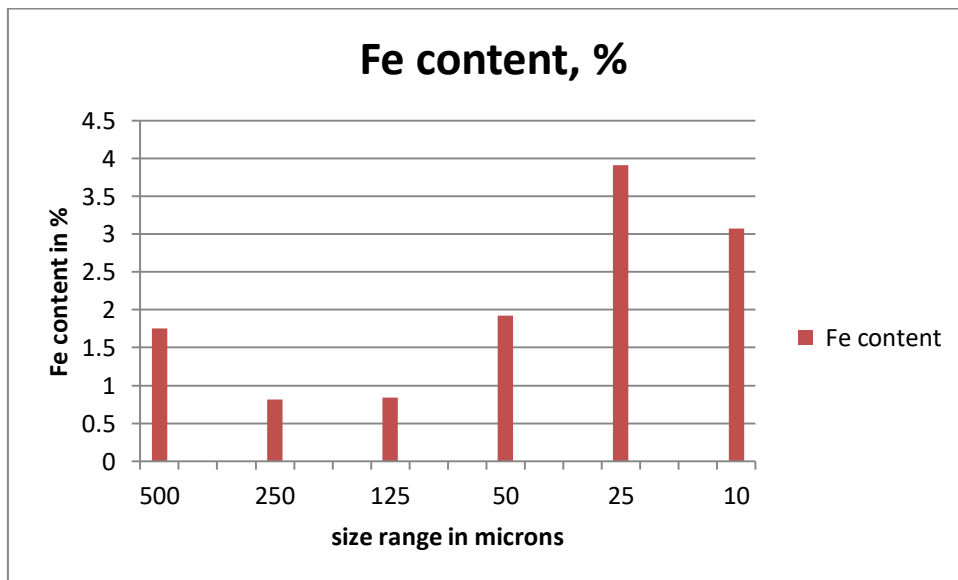


Figure 4-11: Calcium content vs size range of sample 2

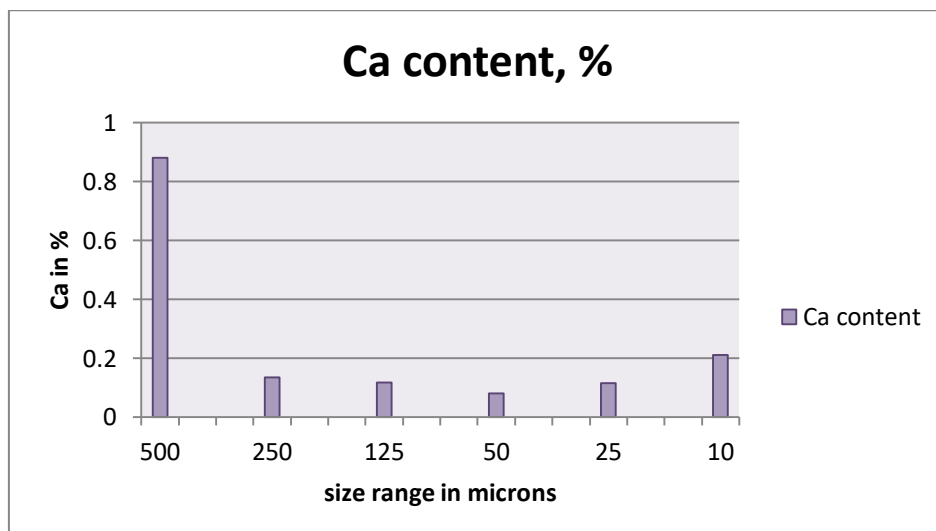


Figure 4-12: Kalium content vs size range of sample 2

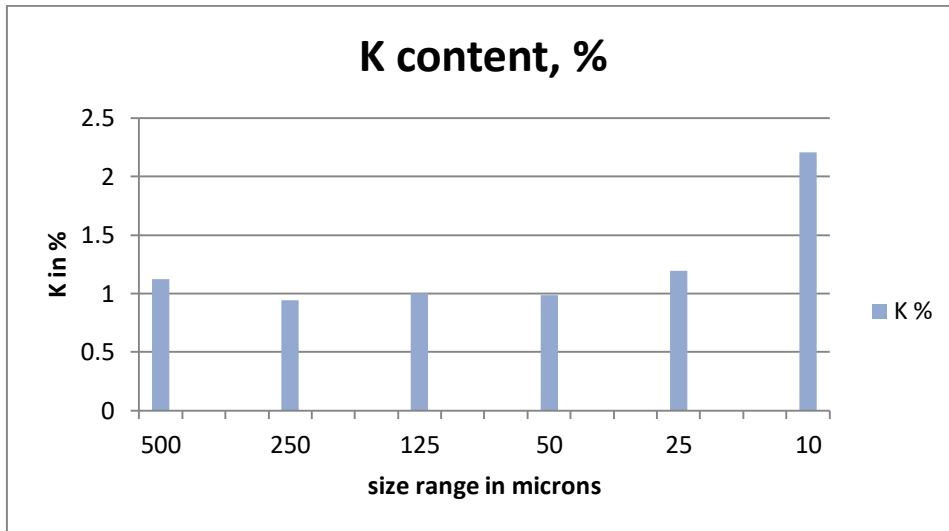


Figure 4-13: Aluminum content vs size range of sample 2

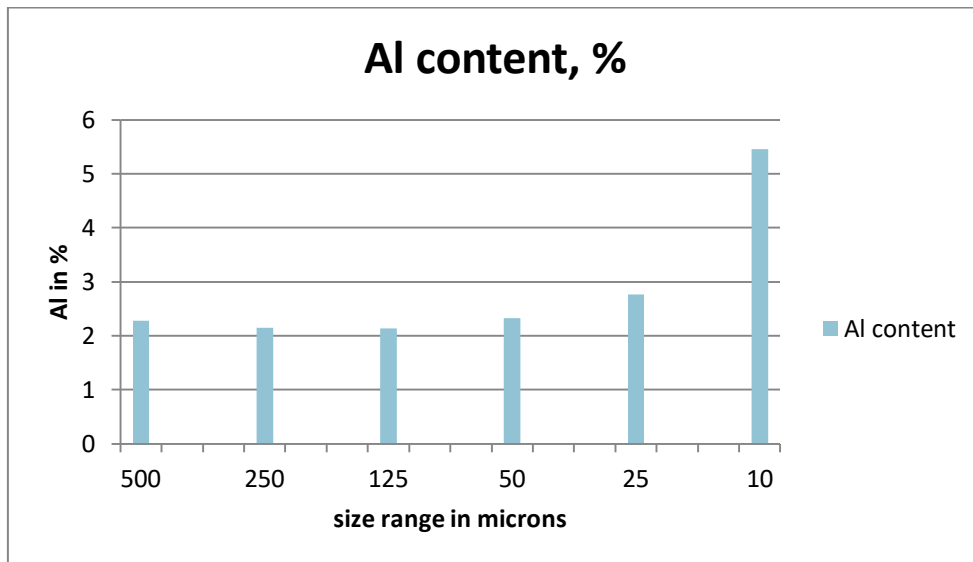
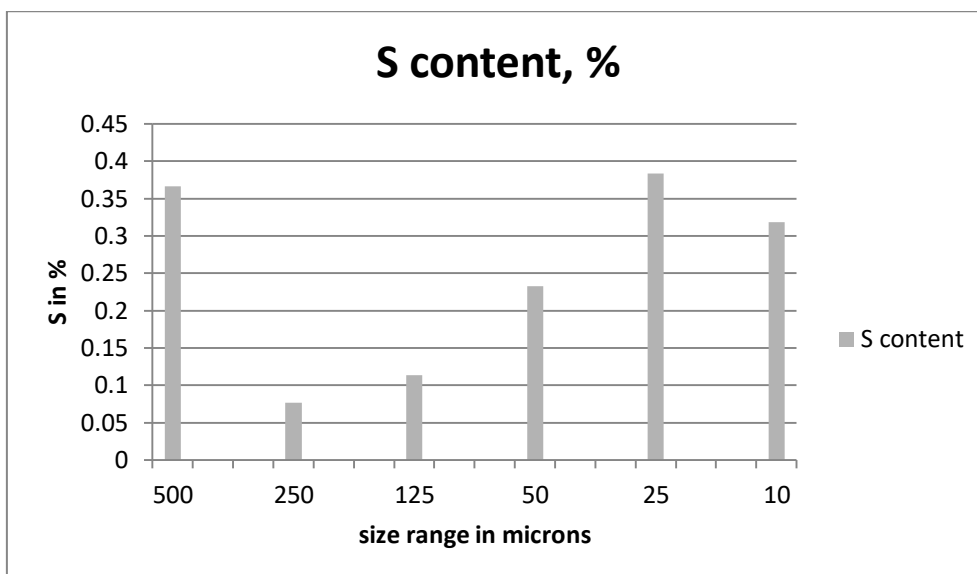


Figure 4-14: Sulfur content vs size range of sample 2



4.2.2.1 Discussion of elemental analysis sample 2

Elemental analysis result has unexpected outcomes:

Balance value which has no attribution to a particular element and analyzer can not recognize which element it is, the balance value of the analysis was too high to reach around 45 % of tailing composition. The reason might be the plastic wrap which used to hold the sample in the sample cup was not suitable for the analysis because it was for food wrapping or commercial usage, it was not for use in XRF analysis. And the thickness of plastic wrap was 12.7 μm and typical wraps used for XRF analysis are polypropylene film with a thickness of 4 μm . So improper wrapping material instead of proper material like polypropylene film was too thick which resulted in unacceptable levels of X-ray attenuation.

The chlorine concentration in tailing was unusually high, but this was not a problem regarding tailing composition. The plastic wrap, which we have used, is made by polyvinyl chloride (PVC) and it results in too much value of chlorine concentration in tailings analysis.

Copper and aluminum content is the high size range of below 25 microns and at the same time at a particle size of above 500 microns, the content was high. Iron and sulfur contents were high at 25 microns.

Above 500 microns, the cumulative obtained mass percentage was so low that we can ignore the high metal content value of the analysis at that size range. If I ignore that, most of the metal content is highest at below 25 microns size range.

It could be observed easily that sulfur and iron distribution have the same curvature along the size ranges meanwhile aluminum, potassium, and calcium curvature have the same manners alongside.

But Copper concentration in tailings distributed opposing other elements, the highest concentrations of copper is at 10 microns and 250 microns.

4.2.3 Discussion of comparison of the two analysis

The copper content in sample 1 was 1039.7 ± 290.8751 ppm on the other hand in sample 2 was 580 ± 81.1 ppm.

Ca content of sample 1 was 0.363 ± 0.0702 % and in sample 2 was 0.256 ± 0.03661 %.

Fe content value in sample 1 was 2.348 ± 0.368 % and in sample 2 was 2.053 ± 0.11083 %.

Sample 1 has Mo content mean value in ppm, 97.95 ± 19.2175 otherwise in sample 2 Mo concentration was too low so that XRF can not detect the value.

In sample 2 analysis, Aluminum has a mean value in %, 2.85 ± 0.4353 , and Sulfur has a mean value in %, 0.248 ± 0.0217 .

Those are the mean values of both samples. I would conclude that copper distribution along the tailing pond is unpredictable and the history of those should be estimated with huge data variables. In other words, the copper content and characteristics of the tailing could not determine with only those two data because the difference is too high and errors have occurred. Further data analysis and data collections are necessary to continue and to check the result of these assumptions that I have made.

Unlike the copper concentration, Calcium and Iron contents are stable and the error is small so that further assumptions can be made. Unfortunately, the Molybdenum concentration in both samples was low so that reprocessing the molybdenum or involving molybdenum in any process would be too risky and might be inefficient.

Iron and sulfur concentration both have the same manner along with particle size, so that may pyrite processing might be a possible method to reprocessing tailings.

Based on the defined characteristics of tailings, suitable reprocessing methods would be discussed through the next chapter 4.3.

4.3 Discussion of possible methods for processing tailings

As for copper mine tailings reprocessing, the copper concentrate production itself has a huge history moreover, the reprocessing of the tailings was not a new idea in this field. Many researchers and mining companies have been working on this topic, and there are so many articles and research papers in mess. Unfortunately, these papers and the project have inefficient results, and even there are feasible studies according to this case, I have not found any model or pilot plant for reprocessing copper mine tailings. During the literature review, I have confused with those many methods, and yet there are no answers to my research question.

As time passing, I have pulled myself together and decided to start the literature review again. For the second time, I have used research methodology to take right and reliable information from reliable sources. This method was a head-to-head approach of analysis and a very effective or organized method for data collection.

In this section of my thesis, I would write the comparison and contrast about the chosen mine tailings processing method. To start the analysis, the key point of the topic has to be chosen. Based on the literature review, I have set up the key points as:

- Copper mine tailing/ Molybdenum mine tailing
- Old mine tailings
- The tailings metal content limit: Cu (1039.7ppm), Fe (2.348%), Mo(97.95 ppm), and Ca (0.363%).
- The recovery should be at least 45%.

Then I have found articles, which match the keyword of the thesis and mentioned in the state of the art section. The methods that can be used, are recycling of tailing as ad-mixture of the current process, bioleaching, electro-remediation, pyrite recovery, and making construction material. Some of them were not possible to use in our case. For example:

Leaching is a good processing method for the recovery of metal, but in our case, the leaching process is too complicated. A leaching process involves gas-solid or liquid-solid phase interaction, on the other hand, our tailing is the liquid-solid phase (slurry), so that the interaction between leaching reagent and mineral can not be calculated or estimated simply. Even if I take dry tailings, an additional grinding process should be done, and the penetration of the reagents would be too slow because the tailings particle size is too fine to penetrate through. So that from a leaching process the most suitable and possible method is bioleaching.

A bioleaching method is very environmentally and economically efficient but, the condition and environment that biological matter survival is very sentimental. In Mongolia where the weather is extreme, the production rate and the operating environment would be restricted due to environmental impact, and the company might have broken in due to the economic loss.

Another possible option is to recycle tailings to the flotation unit as an admixture. This idea is the most successful processing method that is widely used in concentration plant. But the EMC TSF case was already studied in 2015 headed by Yu. P. Nazarov. it would be very inappropriate for using the result of that paper so that I would not mention it. But even the experiment was successfully done EMC has not been used the tailings as ad-mixture. The new process parameters and another stream have to be added to the current stream would complicate the process, and if the

adaptability of the new stream is inefficient, it might result in disqualified products moreover the production may be decreased due to that.

Another advantage of this case is, the reclamation of tailing is not that complicated as other processes, we can add additional pipe in our streams.

Hypothesis 1: Reprocessing tailings with current process flow, selective flotation, is efficient and reaches 60% recovery.

In that case, recycling the tailings to the current stream is possible but I could not prove it is efficient or not. Based on the current strategy of EMC and based on the literature, it is inefficient for the current process. So that hypothesis 1 is false.

Hypothesis 2: To reduce the environmental impact of tailings, pyrite in tailings should be recovered and the selected method is pyrite flotation.

Sulfur has a mean value in %, 0.248 ± 0.0217 . Fe content value in sample 1 was 2.348 ± 0.368 % and in sample 2 was 2.053 ± 0.11083 %. And it concludes that 0.5-1.5% pyrite to be contained in tailings. (Rogozhnikov, 2013)

Possible contents in Tailing which we can use for pyrite flotation, are sulfur and iron. The model plant I chose had a result, where the iron weights 16.12 percent and sulfur weigh 2.71 percent of the total amount. The material they have used in this experiment was the fresh copper tailing. And without any further physical treatment, the tailings fed into rougher, scavenger, cleaner and recleaner flotation in order. The requirement for the pyrite concentration was 80% of pyrite, 4.7 % chalcopyrite, and so on. The recovery of the pyrite can reach 99.1 % with additional collector and frother.

As I was told, the Erdenet Processing plant has pyrite flotation before the bulk flotation and the purpose of that was to clean the feed material of the bulk flotation so that the recovery would be higher, moreover, the overflow (pyrite) of the pyrite flotation was subjected into tailing dam directly. The source was secondary and qualitative, I could not find any quantitative or hard source for this matter. If that is true, there is no point that I worry about the environmental impact due to AMD, while the processing plant dumping the pyrite concentrate directly to tailing dam. But with this thesis, I desperately hope that pyrite recovery should be considered as an economically and environmentally capable process.

The composition of the tailings I have a lower content of iron and sulfur than the model I chose. So may the pyrite recovery would be a little bit complicated and It might not reach the expected pyrite recovery but I can not tell unless I had done some

experiments and had interpretable data. So in my own words, the hypothesis would be false in this case.

Hypothesis 3: The simplest method to reuse tailings is making construction material.

As for the construction material producing with tailings, it would be a great idea while there are no limitations regarding producing construction material. Based on the composition of the material, the processing method can be selected, and the product requirement would be drawn. But the important consideration would be the demand for the construction product and the market research should be done in further development. So I will conclude that hypothesis 3 is true and further investigation should be done.

4.4 Recommendation

4.4.1 Rationale

The reasons for writing this segment are:

- Due to the COVID-19 crisis, the planned additional experiments were not done and I assume that the results of this thesis were lack of experimental data. So, for the sake of development of this thesis further experiments are needed to be done.
- I hope that the thesis and the recommendation would give great instruction or ideas to continue this case with good motivation.

4.4.2 Recommended analysis

- The current results can not determine the feasibility of the reprocessing plant of EMC tailings. To complete this case, the Reflotation experiment was planned to be done and additional particle size analyses and elemental analysis were projected to build a big matrix of tailings history. I recommend splitting this case into, one to develop the reprocessing flotation pilot plant, and another to build a huge matrix of tailings history (Geological and metallurgical mapping).

4.4.2.1 Development on the reprocessing flotation pilot plant

The limitation for this case would be sample size is small and can be prejudicial because the experiment would be done in an early stage of the project development, and the experiment results probably are in shortage. To overcome the limitations, samples should be selected critically, preferred to be small and individual sampling points should be planned, and the sampling and analysis should be done in the early stage so that further process would be one based on metallurgical development and it probably influences the economic decisions applying to the project.

Laboratory feasibility testing purpose

- Define the reasonable flowsheet design and reagent amount and types required to get economic recovery for the desired material
- Investigate possible problems and limitations for a chosen flowsheet
- Establish the assurance to get expected recovery and concentration of the product of the proposed flowsheet

The procedure of Flotation test (Reflotation test used for Tailings)

1. Examine slurry density with Marcy scale (this must be generally between 33-36% percent solid)
2. Weight the mass of feed and dry to recheck the density
3. Measuring pH to make sure if it is in an acceptable range
4. Divide slurry sample into 3 flotation cells for A, B, and C tests
5. In the Refloat test, each tailing sample goes through 3 refloat test.

A test

The first test is performed for 2 min with a pulling rate of 10 sec and an agitator speed of 1200 rpm. No reagent is added in this test and metallurgist uses L shape scraper to collect froth. This is used to check how much copper the plant could have got if the flotation were taken place a little longer. If the retention time is longer, the more copper can be enriched.

B test

The second test is performed by adding frother and collector to make sure if the amount of reagent influenced the flotation process. Other parameters such as time (2min), pulling rate (10 sec), scraper type (L shape), and agitator speed (1200rpm) remain the same.

C test

The third test needs more comminution by tumbling mill for 90 secs to clarify if copper is lost because of insufficient grinding. Reagents are added the same amount as the B test and other parameters remain the same.

6. Filter tailing and concentrate from each flotation test
7. Draining water of the products

Analyze dried tailings and concentrates on flotation tests.

The model methodology for copper flotation pilot plant

The purpose of the study should follow the given aspect and should aim to find these components to build the pilot plant.

Sample characterization: Chemical and mineralogical analysis (elemental analysis), and physical analysis (particle size distribution analysis) and petrography analysis

Rougher flotation optimization: Grinding time and optimal departure size for grinding, reagents and flotation time

Cleaner flotation optimization: number of cleaning stages, cleaner and scavenger flotation time and amount of reagents

Locked cycle test: flowsheet balance, circulation load, recycling water, and final grade and recovery of the product (S.R.Williams, 2002)

The recommendation segment is done here, after the completion of the instructed procedure further development should be done under economic analysis.

5 Conclusion

The increase in quantity and diversity of demand and exhausting resources of metal and metalloid leads to new interest in recycling and paying attention to historical mine waste. So that the mine wastes became a new field for the researcher and great problems to deal with.

Reprocessing of the mine wastes can be very difficult and major struggles because the quantification and element distribution along the three dimensions are almost impossible to obtain and analyze or even to collect data.

In this thesis, tailings of Erdenet Mine Corporation were analyzed and possible methods to reprocessing were defined based on the detailed research.

The distribution of particles can be analyzed by taking the samples from all over the tailing pond area and analyzed with elemental analysis and size distribution analysis. Those processes were done in my thesis, and results were analyzed according to obtained data. It was a great challenge to analyze and to define the characteristics of old tailings with particle size analysis and size distribution analysis. To develop the result, more data should be obtained, and experiments have to be precise.

The methods for reprocessing tailings were compared and the most suitable method was chosen as making construction material and road base material or ceramics. This method was considered economically feasible tailing the reprocessing method and cheaper than other methods.

Reprocessing of tailings has to be efficient in both economic and environmental way.

As a result, further studies should follow these recommendations:

- To ensure the long term mining waste behavior more analysis and data should be obtained
- Data collection has to cover more analysis other than size distribution and elemental analysis such as geochemical analysis, and using geological mapping
- The sampling point should be planned more reasonable and pre-assumption should be made before the sampling
- With this different sampling point, the model of tailing behavior should be built as matrixes
- After these analyses reprocessing the method of tailing should be chosen.

To conclude this thesis, this was a great challenge to built those assumptions, and estimations.

Appendix

Table 1: Particle Size distribution data on sample 1

Sieve size, microns	500	210	150	105	74	45
Cumulative passing %	100	94	85	74	62	54
Incremental weight of retained %	6	9	11	12	8	54

Table 2: Particle size distribution data sample 2

Sieve size, microns	500	250	125	50	25	0
Cumulative passing %	99.7	90.3	54.9	23.3	14.3	0.0
Incremental weight of retained %	0.3	9.4	35.4	31.6	8.9	14.3

Table 3: Elemental analysis result sample 1

	%	ppm	ppm	%	%	ppm	ppm	ppm
	Ca	Co	Cr	Fe	K	Mg	Mn	Mo
P-01	0.38	8	11	2.41	2.64	0.47	260	108
P-02	0.38	7	9	2.16	2.41	0.41	256	92
P-03	0.43	6	8	2.22	2.29	0.43	239	85
P-04	0.51	5	6	1.86	2.29	0.45	260	65
P-05	0.35	12	8	3.44	2.23	0.37	236	138
P-06	0.33	8	6	2.34	2.35	0.39	236	97
P-07	0.32	8	8	2.59	2.32	0.41	217	85
P-08	0.26	8	7	2.43	2.22	0.31	177	99
P-09	0.43	7	10	2.44	2.33	0.43	246	106
P-10	0.38	7	10	2.41	2.29	0.39	249	95
P-11	0.45	8	8	2.6	2.23	0.45	219	105
P-12	0.41	8	8	2.43	2.16	0.41	219	150
P-13	0.3	4	7	1.76	2.33	0.34	183	85
P-14	0.26	7	7	2.41	2.3	0.34	195	106
P-15	0.27	9	6	2.66	2.36	0.36	222	105
P-16	0.31	9	7	2.65	2.47	0.38	234	100
P-17	0.46	7	9	2.08	2.45	0.39	263	85
P-18	0.38	7	9	2.1	2.55	0.38	268	83
P-19	0.33	6	7	2.04	2.44	0.34	238	87
P-20	0.32	5	6	1.93	2.34	0.31	219	83
mean value	0.363	7.3	7.85	2.348	2.35	0.388	231.8	97.95
Standard deviation	0.0702	1.7199	1.4609	0.3681	0.1163	0.0457	0.0258	0.0192

Table 4: Elemental analysis result sample 2

Departure size, μm	Duration, sec	Bal, %	Cu, %	Fe, %	Ca, %	K, %	Al, %	Cl, %	S, %
above 500	33.8	43.7	0.1	1.9	1.0	1.2	2.5	41.9	0.4
	34.2	50.0	0.0	1.4	0.6	0.7	1.1	41.3	0.2
	34.5	40.9	0.1	1.9	1.1	1.4	3.2	40.0	0.5
500-250	30.6	40.8	0.1	1.1	0.1	1.2	2.4	45.3	0.1
	31.6	51.7	0.1	0.7	0.1	0.8	2.2	36.2	0.1
	31.8	54.4	0.1	0.7	0.1	0.8	1.9	34.1	0.1
250-125	31.4	50.1	0.1	0.9	0.1	0.8	1.6	37.1	0.1
	31.6	48.6	0.1	0.8	0.1	1.0	2.2	34.2	0.1
	32.1	48.7	0.1	0.9	0.1	1.2	2.7	34.3	0.2
125-50	31.6	42.7	0.0	1.6	0.1	0.9	2.3	38.5	0.2
	30.9	45.2	0.0	2.2	0.1	1.0	2.5	37.3	0.3
	32.5	46.3	0.0	2.0	0.1	1.0	2.1	37.4	0.2
50-25	30.5	44.0	0.0	3.9	0.1	1.1	2.3	38.6	0.4
	31.5	43.5	0.0	4.0	0.1	1.3	2.7	39.0	0.4
	31.8	42.1	0.0	3.8	0.1	1.2	3.3	38.6	0.4
below 25	39.2	45.3	0.1	3.1	0.2	2.1	5.3	30.6	0.3
	36.8	45.4	0.1	2.9	0.2	2.2	5.7	29.8	0.3
	36.0	41.6	0.1	3.2	0.2	2.3	5.4	34.1	0.3

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